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CONSTRUCTION ZONE DELINEATION

SPECIAL GEOMETRIC SITUATIONS

FINAL REPORT

BY

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16. Abstract The spacing and placement of reflectorized channelizing devices and pavement markings used to maintain traffic through special geometric situations in highway work zones were evaluated from the driver's view. The channelizers used included cones, drums, barricades, vertical panels and concrete barrier curbs. The pavement markings used included removable tape and raised markers. The special geometric situations evaluated were: horizontal and vertical curves, relocated ramps, and pavement dropoffs.

The study was limited to short term and long term maintenance and construction activities performed day and night, dry and wet on roadways with posted speed limits of 55 miles per hour.

A literature search to find ideas from other states, and a survey of professionals with delineation experience were employed to obtain improvement recommendations. A professional subjects review of slides showing experimental treatments on an unopened highway and a driver review of videos showing improved spacing and placement schemes in work zones were performed to determine and verify spacing and placement recommendations by the experienced professionals.

The recommendations called for adjustments from the current practice in New Jersey, within each of the geometric situations.

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SUMMARY

Changes to the standard spacing and placement of reflectorized channelizing devices and pavement markings used to maintain traffic through special geometric situations are recommended as a result of a field and laboratory research project. The channelizers used in the field included cones, drums, barricades, vertical panels, and concrete barrier curbs. The pavement markings included removable tape and temporary raised reflective pavement markers (TRPMs). The special geometric situations considered were: horizontal and vertical curves, relocated ramps, and pavement dropoffs.

The scope of the study was limited to short term and long term maintenance and construction activities performed on roadways with posted speed limits of 55 miles per hour. Experimental setups were photographed or videographed in the day and at night with dry and wet pavements in the field.

The research techniques included: a literature synthesis to use ideas from other research; a questionnaire survey of professionals with delineation experience to make recommendations for improvements, a driver review of slides showing experimental spacing and placement designs on an unopened highway to determine which designs merited further study, and finally a driver review of videos showing improved spacing and placement schemes in actual work zones to verify unopened highway slide results.

Based on the results of the literature search, the survey of professionals, and the driver slide and video surveys, recommendations based on the stronger results are made concerning the preferred way to delineate for drivers at curves, dropoffs and relocated ramps.

Horizontal and Vertical Curves

To keep traffic out of the work area in curves, the present New Jersey practice of spacing drums at twice the speed limit in feet or 110 feet for 55 mph should be continued. However, cones should be spaced 55 feet apart due to their smaller size. If short stripes are used to delineate lanes through a curve, then 2 foot stripes should be employed with 20 foot gaps. When concrete barrier curbs are used, the practice of installing reflectors on top should be continued. Glare screens are also effective and should be considered.

Relocated Entrance Ramps

Relocated entrance ramps are shorter than normal and delineation adjustments are recommended to compensate for the severe geometry. To make relocated entrance ramps more visible to mainline or through drivers, cones should be spaced 20 feet apart to the right of ramp traffic entering the main line when the mainline is maintained with cones. When drums are placed in the main line, drums should be spaced 20 feet apart to the right of ramp traffic. The recommended 20 feet spacing is closer than

the current New Jersey practice which calls for ramp channelizers to be spaced the same as main line channelizers.

Relocated Exit Ramps

Like relocated entrance ramps, relocated exit ramps are shorter than normal and need adjustments to compensate for the severe geometry. In the work zone studies, the length of the relocated exit ramps were only 80 and 180 feet long. To make short relocated exit ramps more visible to exiting main line traffic, seven foot panels should be spaced 20 feet apart with TRPMs spaced 10 feet apart or Type III barricades should be used at a 20 foot spacing on the left of exiting vehicles in the ramp when drums are used in the main line. The recommended 20 foot spacing is closer than the current New Jersey practice which calls for ramp channelizers to be spaced the same as main line channelizers.

The use of 7 foot panels or Type III breakaway barricades in the ramps only is another change from current New Jersey practice, which is to use the same type of channelizer in both the main line and the ramp. In short ramps (180 feet) the larger seven foot panels or barricades are more visible than the drums.

According to the "Work Zone Traffic Control Standards and Guidelines" the ideal relocated exit ramp length is 660 feet for 55 mph. To improve the visibility of long relocated ramps, continue the current New Jersey practice of using main line channelizers spaced 55 feet apart in the ramp. When used in 660 foot ramps the larger barricades are not as effective as drums

since each barricade tended to hide part of the next barricade and obscure the visibility of the ramp, even with a spacing of 110 feet.

Pavement Dropoffs

To keep traffic away from pavement dropoffs in long straight sections, cones or drums should be spaced at twice the speed limit in feet or 110 feet apart for 55 mph speed limits. The 110 foot spacing is a deviation from the current New Jersey practice of spacing drums or cones at the speed limit in feet or 55 feet apart for 55 mph. When using concrete barrier curbs, reflectors should continue to be installed on top of the barrier. When separating lanes of traffic going in the same direction with a solid white stripe, temporary raised reflective markers should be installed and spaced 5 feet apart on the stripe.

IMPLEMENTATION OF FINDINGS

A technical committee composed of professionals involved in construction zone delineation reviewed the issues and the problems initially and provided feedback throughout the project. The maintenance and protection of traffic section of the New Jersey Department of Transportation is using the recommendations made in this study to improve delineation in special geometric situations.

INTRODUCTION

Problem

Channelizers and pavement markings used to maintain traffic through certain geometric situations do not clearly identify the travelled path to the motorist during the approach. A New Jersey study by Davis (1) of 11 construction sites revealed that in some cases drivers said they were caught by surprise and ran into barricades and arrow boards. Bhavsar (2) surveyed 15 New Jersey professionals involved with work safety and found that the issue of spacing and placement was of concern to them. Vanstrum (3) notes that night accidents are on the increase. One possible cause is inadequate visibility. Older drivers, especially, need more luminance than younger drivers. The FHWA (5) notes the need to adjust spacing to account for different sizes of channelizers.

The following special geometric situations were identified from the literature as needing extraordinary roadway delineation treatment in construction zones:

1. Vertical and horizontal curves (5).
2. Relocated ramps (15).
3. Pavement dropoffs (7).

The need for study under adverse conditions such as low sun, nighttime, fog, snow, and rain (4) was also identified.

Scope

The study was limited to delineation within short term and long term maintenance and construction activities performed on roadways with posted speed limits of 55 miles per hour. Experimental setups were photographed or videographed in the day and at night with dry and wet pavements.

Objectives

The motorist must be kept out of work areas. In order to help accomplish this, the channelizers need to be spaced and located in such a way that the message is clear to the driver as to where the closed and the usable lanes are. On the other hand channelizers should not be spaced any closer than necessary to save money. The project was designed to find the best spacing and placement of channelizers and pavement markings in curves, relocated ramps, and dropoffs under various weather and light conditions. It is assumed that visually improved delineation will reduce driver confusion and increase safety in work zones. An important goal is to make recommendations for improvement that can be readily implemented with negligible cost increases.

Method

To improve spacing and placement of reflectorized channelizers and pavement markings, the following techniques were utilized:

1. A literature search to find and use ideas from other research on how to delineate special geometric situations;

2. A survey of professionals experienced in work zone delineation to obtain practical recommendations on the circumstances where improvements are needed or where current practice should be continued;
3. A driver review of slides showing experimental spacing and placement schemes on an unopened highway to determine which designs merited further study; and
4. A driver review of videos showing improved spacing and placement schemes in actual work zones to verify unopened highway experiment results.

LITERATURE REVIEW

A search of the literature revealed some suggestions for delineating vertical and horizontal curves, relocated ramps and pavement dropoffs. Suggestions in the literature were used as input for study in the project.

Vertical and Horizontal Curves - Table 1 lists suggested treatments for maintaining traffic through vertical and horizontal curves. Derived from the suggestions is a need to study: channelizers spaced according to size and road curvature: two foot stripes with 20 feet gaps; and reflective raised pavement markers spaced 20 feet apart as a supplement and 6 to 10 feet apart without paint.

Relocated Ramps - Table 2 lists suggested treatments for relocated ramps. A need to study various types of channelizers spaced as close as 20 feet apart and raised reflective markers spaced 10 feet apart as a stripe supplement or 5 feet apart as a stripe simulator is suggested by the literature.

Pavement Dropoffs - Table 3 lists suggested treatments for long straight sections of pavement dropoffs. A need is suggested to study various types of channelizers spaced as far apart as 500 feet and reflective raised pavement markers spaced as close as 5 feet apart to supplement or simulate a

TABLE 1. SUGGESTED TREATMENTS FOR HORIZONTAL AND VERTICAL CURVES

Delineation Method	Spacing	Source
Channelizers	"Longer or shorter spacings may be desirable depending on the direction and degree of curvature."	Pain (8)
	Vary spacing with the degree of curvature. Table provided.	Hatton (9)
	Space cones closer than other channelizers.	PennDot (10)
Paint	Short stripes should be studied on vertical curves and horizontal curves 2 degrees or more.	Dudek (11)
	Two foot stripes on 20 foot centers are recommended for severe curvature.	FHWA (12)
Raised Pavement Markers	Space raised pavement markers at 20-25 foot intervals on both painted edge and center lines and at 6 to 10 foot intervals without paint.	FHWA (13)
	Place at 20 foot intervals on centerlines with 6 degrees or more of curvature.	FHWA (12)
	Raised pavement markers are more effective than post mounted delineators on isolated horizontal curves.	Stimpson (14)

TABLE 2. SUGGESTED TREATMENTS FOR RELOCATED RAMPS

Delineation Method	Spacing	Source
Channelizers	Typical traffic controls are shown for a freeway exit ramp with channelizers spaced at the speed limit.	Work Zone Traffic Control Standards and Guidelines (15)
	Barricades and drums are to be spaced as close as 20 feet on relocated ramps.	Proposed NJDOT Traffic Control Plans
Paint	Better ramp stripes are needed.	Office of Highway Operations (7)
	"Pavement markings are most effective to indicate lane changes, tapers, diversions and so on."	Better Roads (6)
Raised Pavement Markers	Place at 10 foot intervals as a paint supplement and at 5 foot intervals without paint.	Kahn (16)

TABLE 3. SUGGESTED TREATMENTS FOR PAVEMENT DROPOFFS

Delineation Method	Spacing	Source
Channelizers	Drums do not adequately delineate pavement dropoffs.	Office of Highway Operations (7)
	Channelizers may be spaced up to 500 feet if the pavement dropoff is between 2 1/2 and 4 inches.	PennDot (10)
Paint	8 foot stripe/32 foot gap pattern was rated as the best. 1 and 2 foot stripes on 40 foot centers were as effective as 4 foot stripes on 40 foot centers.	Dudek (17)
Raised Pavement Markers	Drivers rated as effective: 4 non-reflective TRPMs at 3 1/3 feet/30 foot gap with one reflective TRPMs at 80 feet, three non-reflective TRPMs and one reflective TRPMs at 3 1/3 feet/30 foot gap, two non-reflective TRPMs at 4 feet/36 foot gap with one reflective TRPMs centered at each gap. Also, drivers rated the control 4 foot stripe/36 foot gap pattern a inferior to the three TRPMs treatments.	Dudek (17)
	Supplemental TRPMs should be spaced at 40 feet on broken lines and at 20 feet on solid lines. To simulate a solid line the TRPMs should be placed at 10 foot intervals. To simulate broken lines the TRPMs should be placed in a cluster of three spaced at 5 feet with a 30 foot gap.	Khan (16)
	5 feet and 10 feet	Nebraska Department of Roads (18)

solid line. There is no need to further investigate solid or dashed lines in straight sections of pavement dropoffs due to sufficient information already available in the literature.

CURRENT PRACTICE SURVEY

Procedure

Preparations for the current practice survey were made by taking series of driver's view photographic slides of selected typical curves, relocated ramps, and dropoffs, in New Jersey. The driver's view slides were then shown to experienced professionals in the work zone delineation field from within the New Jersey Department of Transportation. These professionals expressed their recommendations for device use, while reviewing the photographs relevant to each question regarding spacing and placement by filling out a structured survey questionnaire. The questions used in the survey and example photographs are shown in the "Results." The group recommendations from the "CURRENT PRACTICE SURVEY" served as an input for the unopened highway experiments.

Results

Responses were received from 25 professionals with delineation experience, and their recommendations are summarized in relation to each question with photographic examples of special situations that accompanied the questions. Interpretations of the results are provided for the group responses.

Closing Lanes In Curves - Day and wet night photographs presented to respondents are shown as Figure 1. and 2. above the summarized results.

1. Type III barricades used as channelizers should continue to be spaced at the speed limit in feet. As an example, at 55 mph the spacing should be 55 feet.
2. Type III barricades should not be preferred for use over other less expensive channelizers.
3. Abbreviated pavement stripes should not be used.
4. The wet night visibility of pavement stripes should be improved. Temporary raised reflective pavement markers should be considered as an alternate to pavement stripes for improved wet night visibility.

Maintaining Lane Closures Through Curves - A day time photograph presented to respondents is shown as Figure 3. above the summarized results.

1. Drums should continue to be spaced at twice the speed limit in feet. As an example, at 55 mph, the drums should be spaced at 110 feet.
2. Drums should continue to be preferred for use over less expensive channelizers.
3. Abbreviated pavement stripes should not be used.
4. The wet night visibility of pavement stripes should be improved. Temporary raised reflective pavement markers should be considered as an alternate to pavement stripes for wet night visibility.

CLOSING LANES IN CURVES

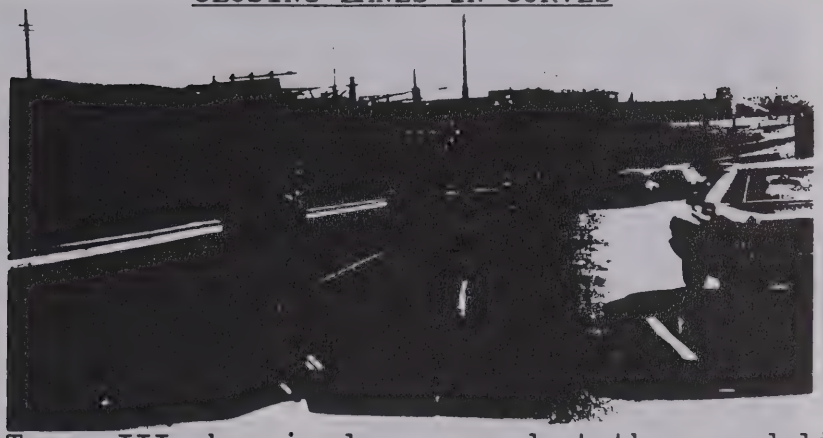

FIGURE 1. Type III barricades spaced at the speed limit in feet closing a lane through a horizontal curve.

1. Should the type III barricades be spaced closer than the current speed limit in feet?

   Response: Yes = 3/25 = 12% No = 20/25 = 80% ? = 2/25 = 8%

Suggestions:	N
a. spacing depends on the lane closed and the direction of the curve.	1
b. 0.75 x speed limit.	1
c. 25 ft.	1
d. 30 ft.	1

2. Should other less expensive channelizers be used to close a lane in a curve?

   Response: Yes = 12/25 = 48% No = 13/25 = 52% ? = 0/25 = 0%

Suggestions:	N
a. drums with panels.	4
b. drums.	3
c. other channelizers on low volume low speed limit highways.	1

3. Should abbreviated pavement stripes be used in place of 10 ft. stripes with 30 ft. gaps to separate lanes of traffic through lane closures in curves?

   Response: Yes = 4/25 = 16% No = 17/25 = 68% ? = 4/25 = 16%

Suggestions:	N
a. solid stripes.	5
b. 10 ft. stripe with 10 ft. gap.	1
c. 20 ft. stripe with 20 ft. gap.	1

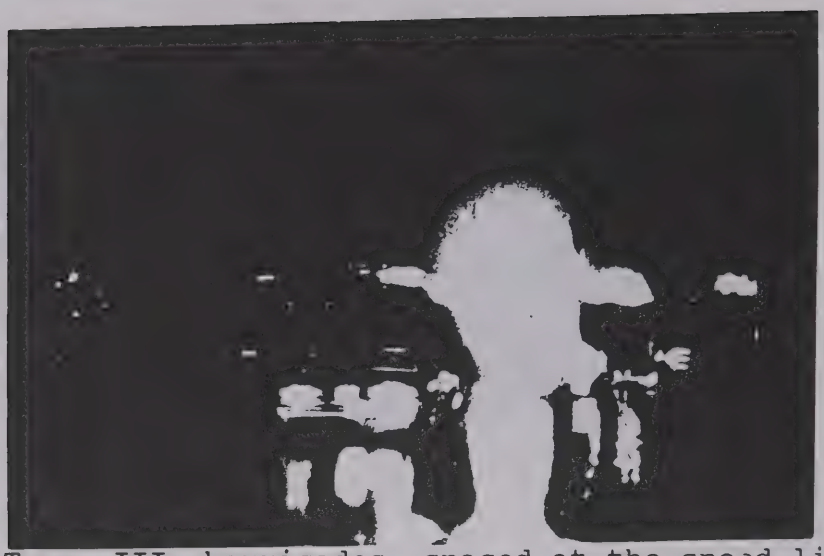

FIGURE 2. Type III barricades spaced at the speed limit in feet closing a lane through a curve at night in the rain.

4. Should the wet night visibility of pavement stripes in lane closures through curves be improved?

Response: Yes = 22/25 = 88% No = 2/25 = 8% ? = 1/25 = 4%

Suggestions:	N
a. temporary raised pavement markers (TRPMs)	10
b. TRPMs with wide stripes.	2
c. wet night visible stripes	2
d. solid stripes	2
e. raised tape with TRPMs	1
f. reduced stripe gap.	1

5. List any other work zone delineation issues concerning lane closures in curves.

	N
a. Improve advanced signing.	4
b. Remove old paint and lens from existing RPMs.	2
c. Place arrow signs on barricades.	1
d. Avoid lane closures in curves; shift to a tangent section.	1
e. Use rumble stripes to reduce speed.	1
f. Enforce speed limits.	1
g. Enforce a 35 mph speed limit.	1

MAINTAINING LANE CLOSURES THROUGH CURVES

FIGURE 3. Drums at twice the speed limit in feet maintaining a lane closure through a curve.

1. Should the drums maintaining lane closures through curves be spaced closer than twice the speed limit in feet?

   Response: Yes = 4/25 = 16% No = 21/25 = 84% ? = 0/25 = 0%

Suggestions:	N
a. speed limit in feet.	2
b. only if required to see 2 or 3 drums at a time.	1
c. change only if lane is not clearly defined.	1
d. 25 ft.	1

2. Should other, less expensive channelizers be used to maintain lane closures through curves?

   Response: Yes = 4/25 = 16% No = 21/25 = 84% ? = 0/25 = 0%

Suggestions:	N
a. depends on the speed limit.	2
b. depends on the volume.	1
c. vertical panels.	1
d. alternate with other devices	1

3. Should abbreviated stripes be used in place of 10 ft. stripes with 30 ft. gaps to maintain lanes of traffic through work areas in curves?

   Response: Yes = 5/25 = 20% No = 18/25 = 72% ? = 2/25 = 8%

Suggestions:	N
a. solid stripes.	3
b. 10 ft. stripe with 10 ft. gap.	1
c. 6 ft. stripe.	1

Relocated Ramps - A day time photograph presented to respondents is shown as Figure 4. above the summarized results.

1. Spacing channelizers at the speed limit in feet should be continued. A closer spacing should be considered.
2. Type III barricades should not be preferred for use over other less expensive channelizers.
3. The wet night visibility of solid stripes used to mark relocated ramps should be improved. TRPMs should be considered as an alternate.

Pavement Dropoffs - Day and wet night photographs of pavement dropoffs are shown in Figure 5. and 6. above the summarized results.

1. Drums should continue to be spaced at the speed limit in feet.
2. Drums should continue to be used in preference to other less expensive channelizers to delineate slight pavement dropoffs.
3. The wet night visibility of the pavement stripes when used next to barrier curbs should be improved. Barrier mounted reflectors or temporary raised reflective pavement markers should be considered as an alternate to stripes.

4. Should the wet night visibility of pavement stripes used to maintain lane closures be improved in curves?

Response: Yes = 21/25 = 84% No = 1/25 = 4% ? = 3/25 = 12%

Suggestions:

	N
a. TRPMs	8
b. TRPMs with wide stripes.	2
c. wet night visible stripes.	2
d. solid stripes.	1

5. List other work zone delineation issues concerning maintaining lane closure through curves

	N
a. lack of edge line visibility when barrier curb is used.	1

RELOCATED RAMPS

FIGURE 4. Relocated entrance ramp channelized with drums spaced at the speed limit in feet.

1. Should drums used to delineate relocated ramps be spaced closer than the current practice (speed limit in feet)?

Response: Yes = 8/25 = 32% No = 15/25 = 60% ? = 2/25 = 8%

Suggestions:

	N
a. 0.50 x speed limit.	3
b. 0.75 x speed limit.	1
c. 25 feet.	1
d. 30 feet.	1
e. depends on length and alignment.	1
f. advance signing.	1
g. ramp speed limit in feet.	1
h. standard spacing rather than speed limit spacing.	1

2. Should other more visible devices be used instead of drums to make relocated ramps more visible through traffic?

Response: Yes = 16/25 = 64% No = 8/25 = 32% ? = 1/25 = 4%

Suggestions:	N
a. Type III barricades.	2
b. low intensity flashing lights.	2
c. improved sight distance (now blocked by mainline drums).	2
d. vertical panels on drums.	2
e. cones with collars on low volume roads.	2
f. Type III barricades with arrow signs on every third.	1
g. delineators on drums.	1
h. advance signing.	1

3. Should the wet night visibility of solid stripes used to mark relocated ramps be improved?

Response: Yes = 22/25 = 88% No = 2/25 = 8% ? = 1/25 = 4%

Suggestions:	N
a. TRPMs	10
b. more flectivity	4
c. TRPMs with wider stripes	1
d. gore cross hatching	1

4. List other work zone delineation issues concerning relocated ramps.

	N
a. improve exit signs	5
b. avoid abrupt geometry	3
c. cover existing signs	1
d. use variable message signs	1
e. close ramp	1

PAVEMENT DROPOFFS

FIGURE 5. Pavement dropoff delineated with drums spaced at the speed limit.

1. Should the drums used to delineate slight pavement dropoffs be spaced at less than the current practice (speed limit in feet)?

   Response: Yes = 5/25 = 20% No = 18/25 = 72% ? = 2/25 = 8%

Suggestions:	N
a. in extreme cases	1
b. twice the speed limit	1
c. three times the speed limit on low speed roads	1
d. 25', 50', 75', or 100'	1

2. Should other, less expensive channelizers be used instead of drums to delineate slight pavement dropoffs?

   Response: Yes = 8/25 = 32% No = 17/25 = 68% ? = 0/25 = 0%

Suggestions:	N
a. traffic stripes	2
b. cones	1
c. inexpensive devices between drums spaced further apart	1
d. raised panels	1
e. depends on severity of dropoff	1

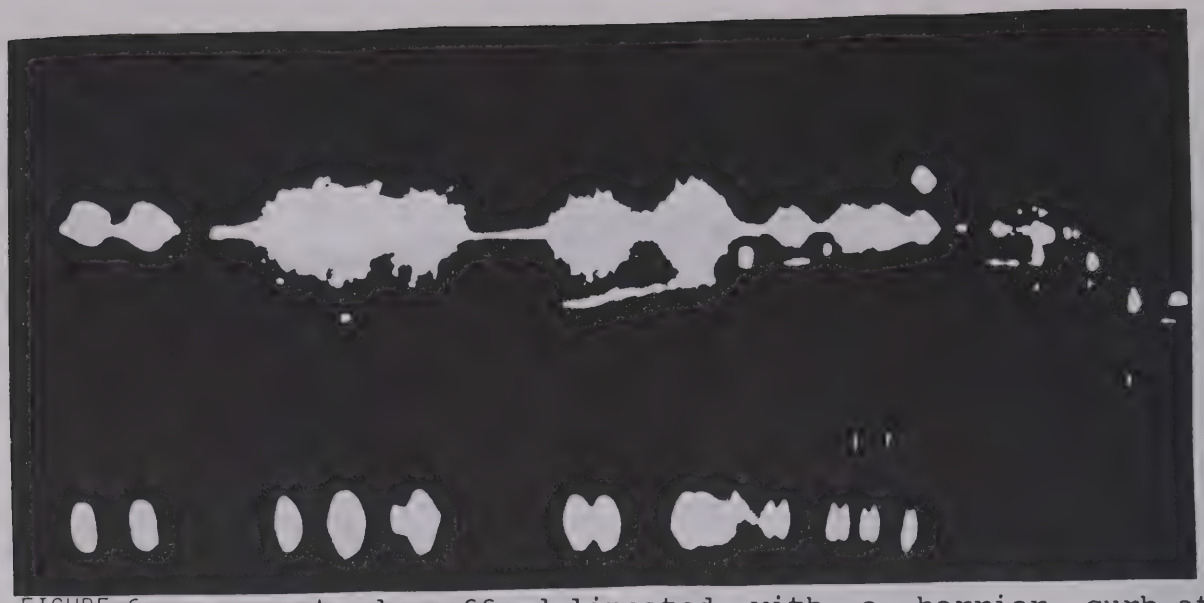

FIGURE 6. pavement dropoff delineated with a barrier curb at night in the rain.

3. Should the wet night visibility of the pavement stripes next to temporary barrier curbs be improved?

Response: Yes = 16/25 = 64% No = 9/25 = 36% ? = 0/25 = 0%

Suggestions:	N
a. barrier reflectors	8
b. temporary raised pavement markers	4
c. TRPMs with wide stripes	1
d. stripe on curb	1
e. wide stripe	1
f. glare screen	1

4. List any other work zone delineation issues concerning pavement dropoffs.

	N
a. use escape ramps	3
b. use drums for servere dropoffs	2
c. eliminate dropoffs	2
d. use advance signs warning of dropoffs	2
e. use variable message signs	1
f. use wedge shaped edge at dropoff	1
g. use barrier curbs for extremely long dropoffs	1
h. penalize contractor for violating plan details	1
i. enforce a 35 mph speed limit	1
j. should work zone delineation be stronger than permanent delineation?	1

OTHER SPECIAL GEOMETRIC SITUATIONS

1. List any other special geometric situations you feel could be improved with delineation.

	N
a. rural highways with substandard shoulder width.	1
b. rural highways with sinuous vertical or horizontal alignment	1
c. crossovers	1
d. temporary detours	1
e. pavement lane drops	1

UNOPENED HIGHWAY SLIDE REVIEW EXPERIMENTS

Procedure

A total of 79 drivers were selected from the New Jersey Department of Transportation to view day and night slides of special geometric situations installed on unopened New Jersey state highway Route 55 and asked to respond to predeveloped questions by filling out structured survey response forms. Table 4 shows the age and sex distribution of the driver group. The responses from these drivers help to determined which spacing and placement designs should receive further study in work zones.

The driver subjects viewed 218 slides photographed as follows:

1. At entrance ramps 495', 220', and 0' from the gore tip.
2. At exit ramps 1000', 495', and 220' from the gore tip.
3. At curves and dropoffs with closures to the left or to the right of the driver.

The slides were presented in a randomized order within each of the categories. The day slides were shown before the night slides.

Following a practice session, the subjects had 5 seconds to view each slide and check their response on a form. The presentation procedure was designed to see how well the driver

TABLE 4. SLIDE REVIEW SUBJECT DISTRIBUTION

Age	Male	Female	Total	%
20-29	1	6	7	9
30-39	9	7	16	20
40-49	13	9	22	28
50-59	13	7	20	25
60 and over	5	9	14	18
Total	41	38	79	100

could detect the ramps, curves, and dropoffs shown different spacings of the traditional and innovative channelizing and marking devices and rate the spacings by choosing whether "TOO CLOSE," "ADEQUATE," or "TOO FAR." The sample survey forms are shown in Appendix A.

Duncan's Multiple Range Test was used with an alpha of 0.05 to analyze the data. Means were assigned a rank by letter, an "A" being the highest score. Means with the same letter are not significantly different from each other. A "B" score would be significantly inferior to an "A" score.

Results

Horizontal Curves - Cones and drums were spaced 55, 110, and 220 feet apart on unopened highway curves. The cones 55 feet apart, the drums 55 feet apart and the drums 110 feet apart were judged as being equivalent to each other. Longer cone and drum spacings were not judged to be as visually effective. The different treatments are shown in Figures 7 through 12, and the results are summarized in Table 5.

Two foot stripes with a 20 foot cycle were studied in a horizontal curve. These stripes are allowed by the MUTCD, 1988 edition, for work zones up to two weeks in duration. The subjects preferred the 20 foot cycle over the 40 foot cycle. Figures 13 and 14 illustrate the 20' treatment and Figures 15 and 16 show the 40 foot cycle for comparison. The results are summarized in Table 6.

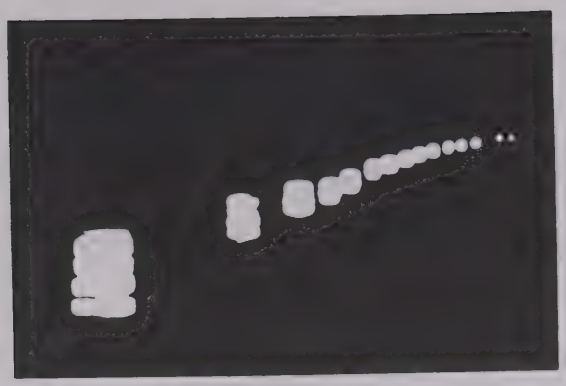

Figure 7. Horizontal curve with drums 55'apart.

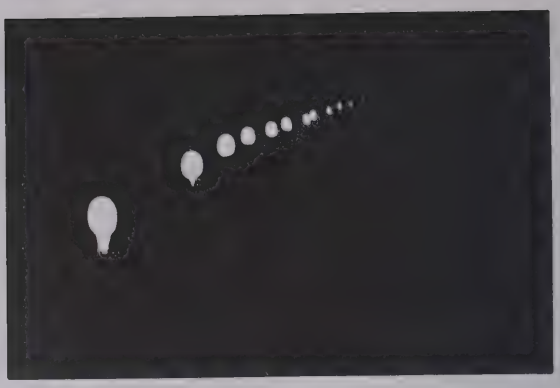

Figure 8. Horizontal curve with cones 55' apart.

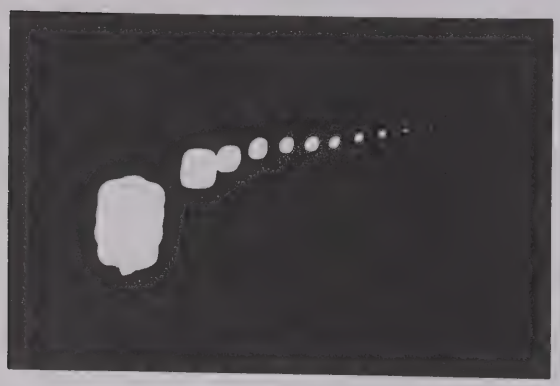

Figure 9. Horizontal curve with drums 110' apart.

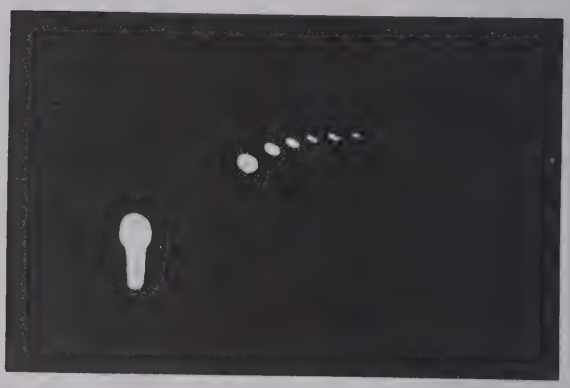

Figure 10. Horizontal curve with cones 110'apart.

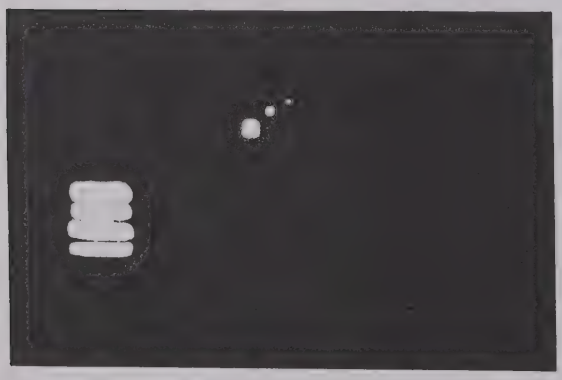

Figure 11. Horizontal curve with drums 220' apart.

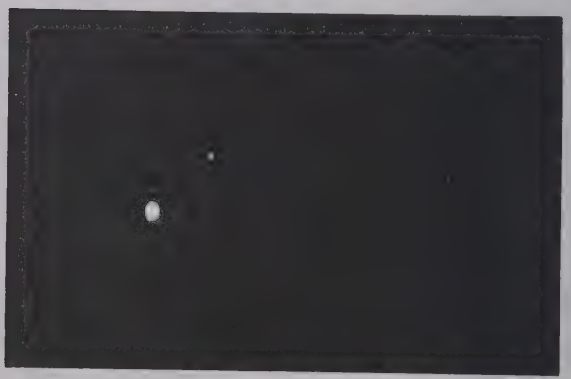

Figure 12. Horizontal curve with cones 220' apart.

TABLE 5. CONES AND DRUMS IN HORIZONTAL CURVES IN THE DAY AND AT NIGHT

Device	Percent Neither too Close Together Nor Too Far Apart	N	Rank *
Drums 55' apart	68	63	A
Cones 55' apart	72	100	A
Drums 110' apart	74	81	A
Cones 110' apart	61	18	B
Drums 220' apart	36	63	C
Cones 220' apart	19	63	D

* Duncan's Multiple Range Test.
Means with the same letter are not significantly different (Alpha = 0.05)

Drums 55' apart, cones 55' apart and drums 110' apart are rated as superior to cones 110' apart which are superior to drums 220' apart which are superior to cones 220' apart.

Figure 13. 2' stripes 20' apart on a horizontal curve in the day.

Figure 14. 2' stripes 20' apart on a horizontal curve at night.

Figure 15. 2' stripes 40' apart on a horizontal curve in the day.

Figure 16. 2' stripes 40 apart on a horizontal curve at night.

TABLE 6. 2 FT. STRIPES 40 FT. APART IN HORIZONTAL CURVES COMPARED WITH 2 FT. STRIPES 20 FT. APART IN THE DAY AND AT NIGHT

	Percent Neither Too Close Together Nor Too Far Apart	N	Rank *
Spacing			
20 ft.	71	54	A
40 ft.	48	54	B

* Duncan's Multiple Range Test.
Means with the same letter are not significantly different
(Alpha = 0.05)

Vertical Curves - The New Jersey standard spacing of twice the speed limit in feet for any channelizer may not be sufficient to maintain a lane closure through a vertical curve. The standard spacing is not supported by the results. Cones were spaced 55, 110 and 220 feet apart. The cones spaced 55 feet apart were judged as being superior to the cones spaced 110 and 220 feet apart and the drums spaced 220 feet apart. The different treatments are shown in Figures 17 through 22 and the results are summarized in Table 7.

Relocated Entrance Ramps - Relocated entrance ramps are shorter than normal and need adjustments to compensate for the severe geometry. To find a way to make relocated entrance ramps more visible to main line drivers so that they can prepare for merges, the ramp channelizers and their spacings were varied in the experiments.

Longer spacing for larger than for smaller channelizers was judged to be needed. When cones were used in the tangent or main line, the ramp placed cones 20 feet apart were judged as being equivalent to the ramp placed drums 20 feet apart. When drums were used in the main line, ramp placed drums 20 feet apart were judged as being equivalent to ramp placed Type III breakaway barricades 60 feet apart. The ramp geometrics used in New Jersey are illustrated in Figure 23, some of the different treatments are shown in Figure 24 through 28, and the results are summarized in Table 8.

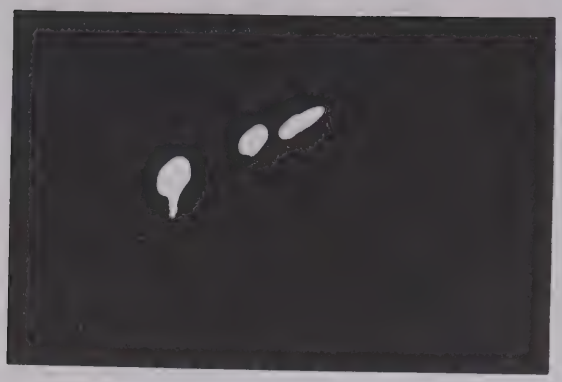

Figure 17. Vertical curve with cones at 55'apart at night.

Figure 18. Vertical curve with cones 55' apart in the day.

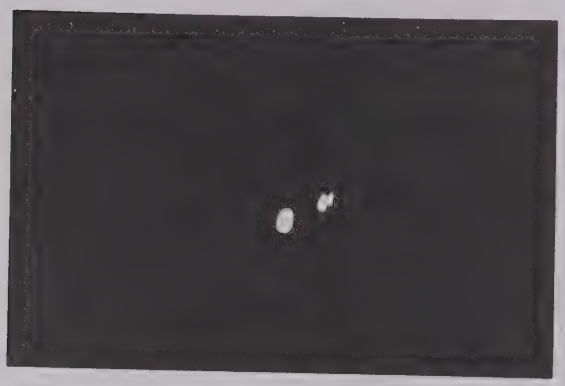

Figure 19. Vertical curve with cones 110' apart. at night.

Figure 20. Vertical curve with cones 110' apart in the day.

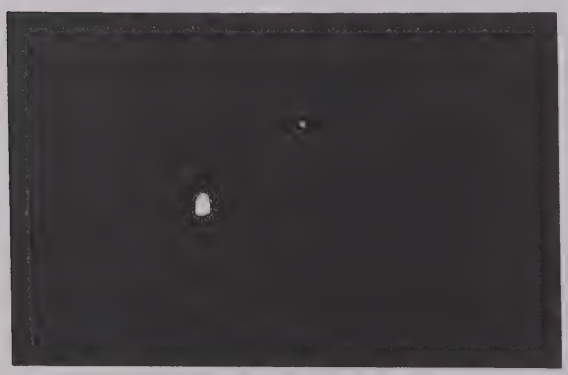

Figure 21. Vertical curve with cones 220' apart at night.

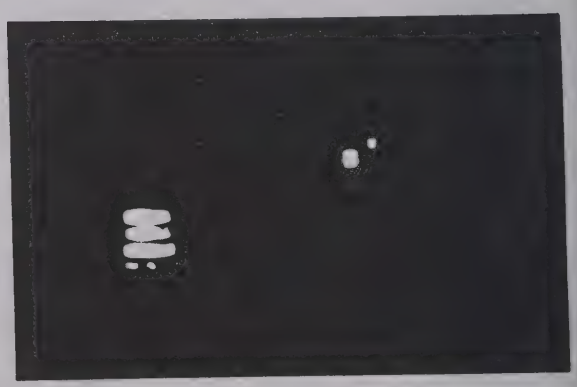

Figure 22. Vertical curve with drums 220' apart at night.

TABLE 7. CONES AND DRUMS IN VERTICAL CURVES IN THE DAY AND AT NIGHT

Device and Spacing	Percent neither too close together nor too far apart	N	Rank *
Drums 55' apart	not studied	not studied	not studied
Cones 55' apart	69	108	A
Drums 110' apart	not studied	not studied	not studied
Cones 110' apart	37	27	B
Drums 220' apart	14	63	C
Cones 220' apart	10	72	C

* Duncan's Multiple Range Test. Means with the same letter are not significantly different. (Alpha = 0.05)

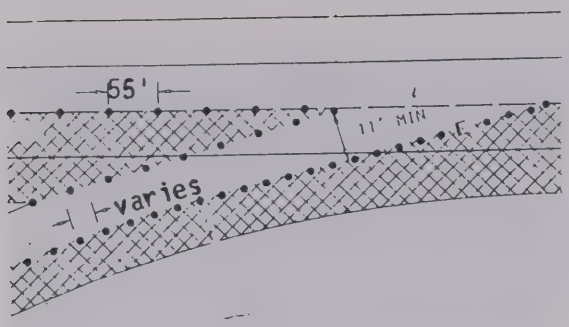

Figure 23. Entrance ramp geometrics used in New Jersey.

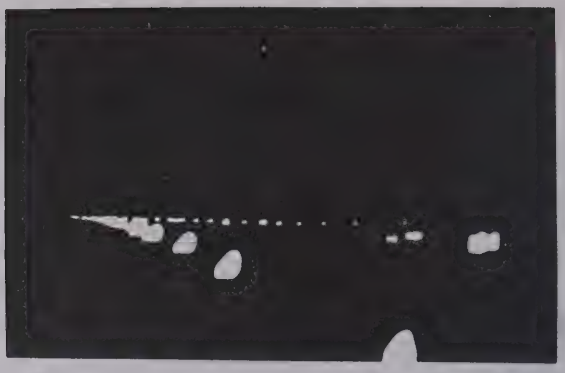

Figure 24. Cones 55' apart in the tangent and cones 20' apart in the ramp.

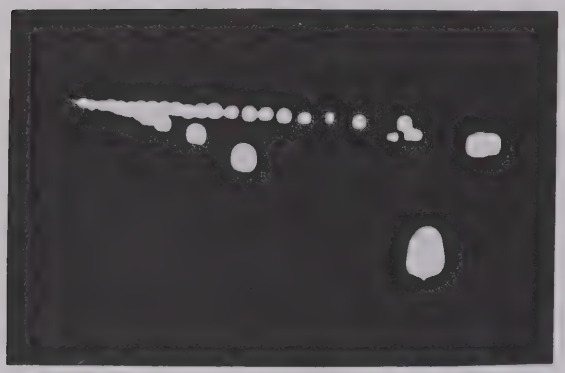

Figure 25. Cones 55' apart in the tangent and drums 20' apart in the ramp.

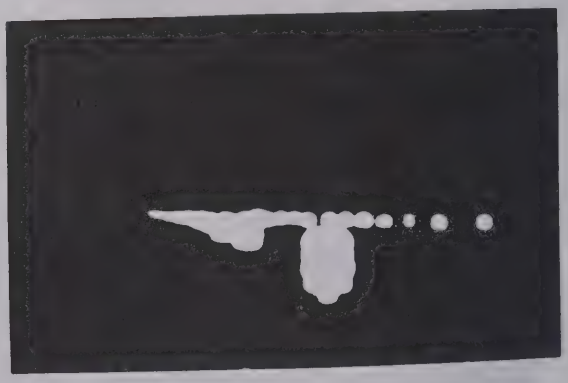

Figure 26. Drums 55' apart in the tangent and drums 20' apart in the ramp.

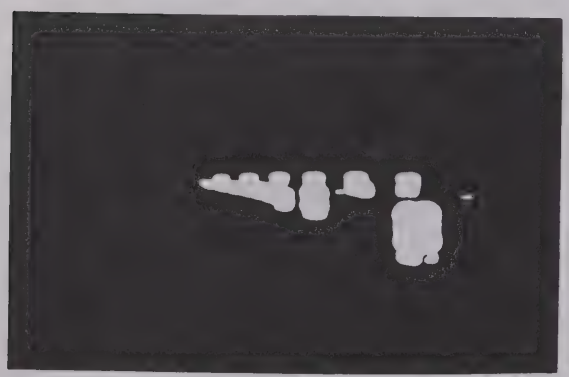

Figure 27. Drums 55' apart in the tangent and Type III barricades 60' apart in the ramp.

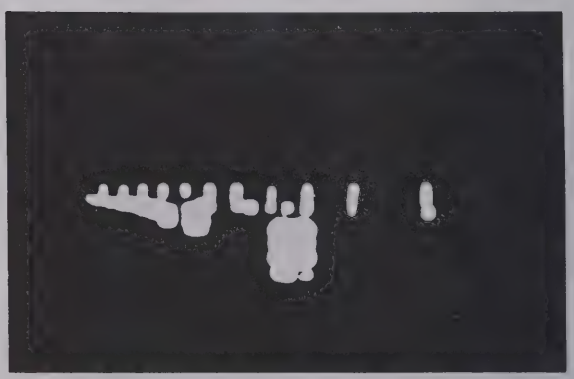

Figure 28. Drums 55' apart in the tangent and 7' vertical panels 40' apart in the ramp.

TABLE 8. RELOCATED ENTRANCE RAMPS AT NIGHT FROM 495, 220 AND 0 FT. FROM THE GORE

Ramp Design	Percent Able To Locate Ramp	N	Rank *
Cones 55' apart in the tangent cones 20' apart in the ramp	44	15	A
Cones 55' apart in the tangent and drums 20' apart in the ramp	41	15	A
Drums 55' apart in the tangent and drums 20' apart in the ramp	37	15	A
Drums 55' apart in the tangent and Type III barricades 60 ft. apart in the ramp	33	15	A
Drums 55' apart in the tangent and 7 ft. vertical panels 40 ft. apart in the ramp	28	15	B

* Duncan's Multiple Range Test.
Means with the same letter are not significantly different (Alpha = 0.05).

Relocated Exit Ramps - Like relocated entrance ramps, relocated exit ramps are shorter than normal and the channelizers need adjustments to compensate for the severe geometry. The 660 foot long ramp was suggested by the "Work Zone Traffic Control Standards and Guidelines" (15). To improve the visibility of relocated exit ramps for exiting motorists, the ramp channelizers and their spacings were varied in the experiments. The spacing for larger devices was longer than the spacing for smaller channelizers.

The longer spacing for larger channelizers is not supported by the results. When cones were used in the tangent or main line, the ramp cones 55 feet apart were judged as being equivalent to the ramp drums 55 feet apart. When drums were used in the main line, ramp drums 110 feet apart were judged as being equivalent to ramp Type III breakaway barricades 110 feet apart or 7 foot high vertical panels 110 feet apart. The ramp geometrics are illustrated in Figure 29, some of the different treatments are shown in Figure 30 through 34, and the results are summarized in Table 9.

Pavement Dropoffs - Motorists need to be warned when they are near a dangerous pavement dropoff. Since dropoffs can often occur on long stretches of straight road there is a possibility that the New Jersey standard spacing of the speed limit in feet is too close.

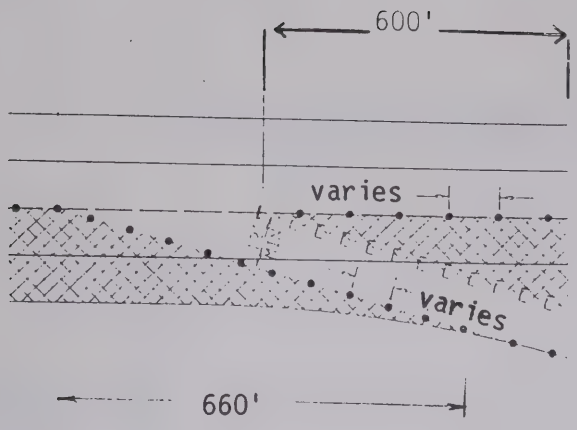

Figure 29. Exit ramp illustrated in "Work Zone Traffic Control Standards and Guidelines." (15)

Figure 30. Cones 55' apart in the tangent and cones 55' apart in the ramp.

Figure 31. Cones 55' apart in the tangent and drums 55' apart in the ramp.

Figure 32. Drums 110' apart in the tangent and drums 110' apart in the ramp.

Figure 33. Drums 110' apart in the tangent and Type III barricades 100' apart in the ramp.

Figure 34. Drums 110' apart in the tangent and 7' vertical panels 110' apart in the ramp.

TABLE 9. RELOCATED EXIT RAMPS IN THE DAY AND AT NIGHT FROM 1000, 495 AND 220 FT. FROM THE GORE

	Percent Able To Locate Ramp	N	Rank *
Ramp Design			
Cones 55' apart in the tangent and cones 55' apart in the ramp	57	30	A
Cones 55' apart in the tangent and drums 55' apart in the ramp	52	30	A
Drums 110' apart in the tangent and drums 110' apart in the ramp	40	30	B
Drums 110' apart in the tangent and Type III barricades 110 ft. apart in the ramp	39	30	B
Drums 110' apart in the tangent and 7 ft. vertical panels 110 ft. apart in the ramp	31	30	B

* Duncan's Multiple Range Test.
Means with the same letter are not significantly different (Alpha = 0.05).

Cones were spaced 55, 110 and 220 feet apart, and drums were spaced 110 and 220 feet apart. The cones spaced 110 feet apart were judged as being equivalent to the drums spaced 110 feet apart. Both treatments were judged as being superior to the cones 55 and 220 feet apart and the drums 220 feet apart. The standard spacing is not supported by the results. The different treatments are shown in Figures 35 through 40 and the results are summarized in Table 10.

Figure 35. Pavement dropoff with cones 55' apart in the day.

Figure 36. Pavement dropoff with cones 55' apart.

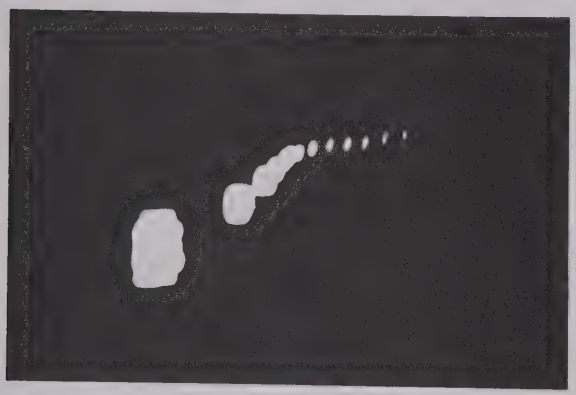

Figure 37. Pavement dropoff with drums 110'apart.

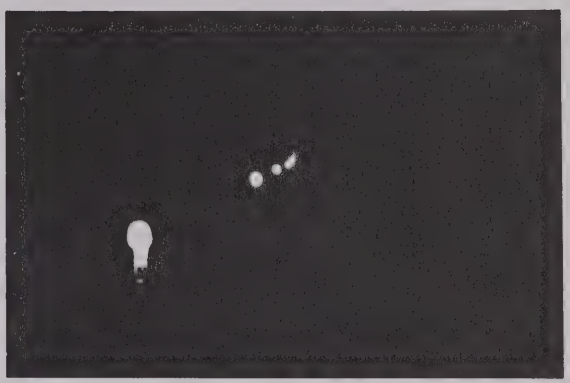

Figure 38. Pavement dropoff with cones 110' apart.

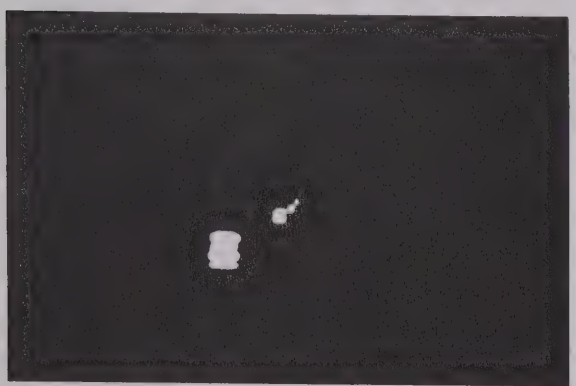

Figure 39. Pavement dropoff with drums 220' apart.

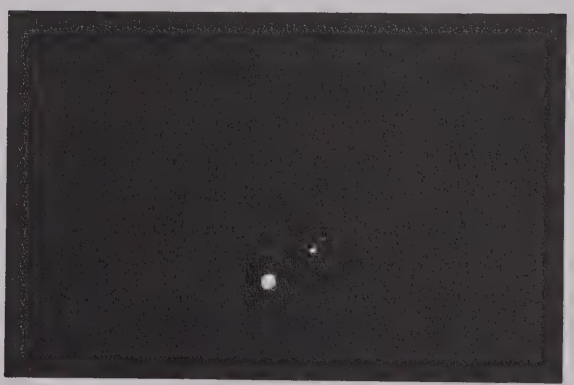

Figure 40. Pavement dropoff with cones 220' apart.

TABLE 10. CONES AND DRUMS IN PAVEMENT DROPOFFS IN THE DAY AND AT NIGHT

Device and Spacing	Percent neither too close together nor too far apart	N	Rank *
Drums 55' apart	not studied	not studied	not studied
Cones 55' apart	65	144	B
Drums 110' apart	73	45	A
Cones 110' apart	71	36	A
Drums 220' apart	40	63	C
Cones 220' apart	18	90	D

* Duncan's Multiple Range Test. Means with the same letter are not significantly different. (Alpha = 0.05)

ACTUAL WORK ZONE VIDEOTAPE REVIEW EXPERIMENTS

Procedure

Day and night videotapes of approaches to sites showing improved delineation used in actual work zones on interstates 95 and 295 were shown to 15 driver subjects. The video review subject distribution by age and sex is shown in Table 11. The site scenes were separated into curves, ramps, and dropoffs and then randomized within each category. Day scenes were shown before night scenes. Driver subjects were instructed to observe the video and mark their opinions on the form in Appendix B. They rated the delineation effectiveness as "excellent," "good," "average," "poor," or "very poor."

Results

Horizontal Curves - Drums and concrete barrier curbs were studied under day and night, with left lane and right lane closures, and with and without street lights.

Table 12 shows that concrete barrier curbs are rated as "good" and as "excellent" with glare screens in delineating where the closed lane is. Drums when spaced 80 or 160 feet apart were rated as "average."

Relocated Entrance Ramp - Only one entrance ramp was taped in the day. As Table 13 shows, the ramp and the main line were delineated with drums spaced 80 feet apart.

The observers felt that the ramp visibility was "average."

TABLE 11. VIDEO REVIEW SUBJECT DISTRIBUTION

Age	Male	Female	Total	%
20-29				
30-39	3	2	5	33
40-49	4	1	5	33
50-59	3	1	4	27
60 and over				

TABLE 12. SUBJECT EVALUATION OF THE EFFECTIVENESS OF CHANNELIZERS IN HORIZONTAL CURVES IN ACTUAL WORK ZONES

Channelizer	Spacing (ft.)	N	Score	Rank*
Concrete barrier curb with glare screen	continuous	15	25	1
Concrete barrier curb	continuous	15	33	2
Drums	80	15	39	3
Drums	160	15	44	3

* 1 = excellent, 2 = good, 3 = average, 4 = poor and 5 - very poor. The highest score would be 15 x 1 = 15 and the lowest score would be 15 x 5 = 75.

TABLE 13. SUBJECT EVALUATION OF THE EFFECTIVENESS OF RELOCATED RAMPS IN ACTUAL WORK ZONES

Ramp Geometry	Lighting	Tangent Device	Tangent Spacing (Ft.)	Ramp Device	Ramp Spacing (Ft.)	N	Score	Rank *
Relocated entrance	day	drums	80	drums	80	15	46	3
Relocated exits								
180 ft. long	day	drums	80	drums	20	15	36	3
	night with street lights	drums	80	drums	20	15	53	4
	night with street lights	drums TRPMs	80 20	7 ft.panels TRPMs	20 10	15	43	3
	night with street lights	drums	80	Type III barricades	20	15	45	3
80 ft. long	day	drums	80	drums	20	15	57	4
	night with street lights	drums	80	drums	20	15	73	5

* 1 = excellent, 2 = good, 3 = average, 4 = poor and 5 = very poor.
The highest score would be 15 x 1 = 15 and the lowest 15 x 5 = 75.

Relocated Exit Ramps - In Table 13 a 180 foot long ramp was treated with seven foot vertical panels 20 feet apart with raised pavement markers 20 feet apart in the main line and 10 feet apart in the ramp, Type III barricades 20 feet apart or drums 20 feet apart. In all cases the main line was delineated at least with drums 80 feet apart.

The 7 foot panels with TRPMs and the Type III barricades at night were scored about the same (average) as far as how well an exiting driver could see the exit. The drums 20 feet apart at night were not as effective (poor) as the 7 foot panels with TRPMs or the Type III barricades.

The drums spaced 20 feet apart at the 180 foot ramp in the day were rated "average" while the drums 20 feet apart at night were rated "poor". The same day/night difference is seen at the 80 foot long ramp setup.

Also, the negative effects of the same treatment at a shorter ramp are noted since the 80 foot ramp with drums 20 feet apart was rated 57 (poor) and the 180 foot ramp with drums 20 feet apart was rated 36 (average).

Pavement Dropoffs - Drums, cones, and concrete barrier curbs were studied in day and night, and left lane and right lane closure conditions with single lanes remaining.

Table 14 shows that drums 80 feet apart and concrete barrier curbs were rated as "good" in guiding the driver past a pavement dropoff. The drums 160 feet apart were rated as "average," and the cones 160 feet apart were rated as "poor."

TABLE 14. SUBJECT EVALUATION OF THE EFFECTIVENESS OF CHANNELIZERS IN PAVEMENT DROPOFFS IN ACTUAL WORK ZONES

Channelizer	Spacing (ft.)	N	Score*	Rank
Drums	80	15	32	2
Concrete barrier curb	reflector on top at 100 feet	15	33	2
Drums	160	15	41	3
Cones	160	15	55	4

* 1 = excellent, 2 = good, 3 = average, 4 = poor and 5 = very poor. The highest score would be 15 x 1 = 15 and the lowest score would be 15 x 5 = 75.

A pavement dropoff with two lanes in the same direction was also studied. Temporary foam rubber raised markers (TRPMs) were installed on the solid white tape between the two lanes. Table 15 shows that there was not much of a difference between the tape with the markers (good) and the tape without markers (good) on a dry night. On a rainy night the tape with markers was rated as "average" while the tape alone was rated as "very poor." The use of tape with TRPMs is supported with these results, based upon their effectiveness on wet nights.

TABLE 15. SUBJECT EVALUATION OF THE EFFECTIVENESS OF SOLID STRIPES WITH NEW TEMPORARY MOUNTED RAISED MARKERS IN ACTUAL WORK ZONES

Pavement Marking	Spacing (ft).	Weather	Lighting	N	Score	Rank
Tape with TRPMs	continuous 5	dry	night, street lights	15	28	2
Tape only	continuous	dry	night, street lights	15	30	2
Tape with TRPMs	continuous 5	rain	night, street lights	15	37	3
Tape only	continuous	rain	night, street lights	15	71	5

* 1 = excellent, 2 = good, 3 = average, 4 = poor and 5 = very poor. The highest score would be 15 x 1 = 15 and the lowest score would be 15 x 5 = 75

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APPENDIX A. SLIDE REVIEW FORMS

First, a little about yourself

Are you a male ☐

or female ☐

Do you use corrective lenses for driving ☐ yes ☐ no

Do you use corrective lenses for reading ☐ yes ☐ no

For how many years have you had a US drivers license? _____

In what state is your current license valid? _____

What is your age? _____

PLEASE CHECK ONE

1	TOO CLOSE	ADEQUATE	TOO FAR
2	TOO CLOSE	ADEQUATE	TOO FAR
3	TOO CLOSE	ADEQUATE	TOO FAR
4	TOO CLOSE	ADEQUATE	TOO FAR
5	TOO CLOSE	ADEQUATE	TOO FAR
6	TOO CLOSE	ADEQUATE	TOO FAR
7	TOO CLOSE	ADEQUATE	TOO FAR
8	TOO CLOSE	ADEQUATE	TOO FAR
9	TOO CLOSE	ADEQUATE	TOO FAR
10	TOO CLOSE	ADEQUATE	TOO FAR
11	TOO CLOSE	ADEQAUTE	TOO FAR
12	TOO CLOSE	ADEQUATE	TOO FAR
13	TOO CLOSE	ADEQUATE	TOO FAR
14	TOO CLOSE	ADEQUATE	TOO FAR
15	TOO CLOSE	ADEQUATE	TOO FAR

APPENDIX B. VIDEO REVIEW FORMS

First, a little about yourself

Are you a male ☐

or female ☐

Do you use corrective lenses for driving ☐ yes ☐ no

Do you use corrective lenses for reading ☐ yes ☐ no

For how many years have you had a US drivers license? _____

In what state is your current license valid? _____

What is your age? _____

PLEASE CHECK ONE

SCENE	EXCELLENT	GOOD	AVERAGE	POOR	VERY POOR
1	1	2	3	4	5
2	1	2	3	4	5
3	1	2	3	4	5
4	1	2	3	4	5
5	1	2	3	4	5
6	1	2	3	4	5
7	1	2	3	4	5
8	1	2	3	4	5
9	1	2	3	4	5
10	1	2	3	4	5
11	1	2	3	4	5
12	1	2	3	4	5
13	1	2	3	4	5
14	1	2	3	4	5
15	1	2	3	4	5

PLEASE CHECK ONE

SCENE	EXCELLENT	GOOD	AVERAGE	POOR	VERY POOR
16	1	2	3	4	5
17	1	2	3	4	5
18	1	2	3	4	5
19	1	2	3	4	5
20	1	2	3	4	5
21	1	2	3	4	5
22	1	2	3	4	5
23	1	2	3	4	5
24	1	2	3	4	5
25	1	2	3	4	5
26	1	2	3	4	5
27	1	2	3	4	5
28	1	2	3	4	5
29	1	2	3	4	5
30	1	2	3	4	5

PLEASE CHECK ONE

SCENE	EXCELLENT	GOOD	AVERAGE	POOR	VERY POOR
31	1	2	3	4	5
32	1	2	3	4	5
33	1	2	3	4	5
34	1	2	3	4	5
35	1	2	3	4	5
36	1	2	3	4	5
37	1	2	3	4	5
38	1	2	3	4	5
39	1	2	3	4	5
40	1	2	3	4	5
41	1	2	3	4	5
42	1	2	3	4	5
43	1	2	3	4	5
44	1	2	3	4	5
45	1	2	3	4	5

PLEASE CHECK ONE

SCENE	EXCELLENT	GOOD	AVERAGE	POOR	VERY POOR
46	1	2	3	4	5
47	1	2	3	4	5
48	1	2	3	4	5
49	1	2	3	4	5
50	1	2	3	4	5
51	1	2	3	4	5
52	1	2	3	4	5
53	1	2	3	4	5
54	1	2	3	4	5
55	1	2	3	4	5
56	1	2	3	4	5
57	1	2	3	4	5
58	1	2	3	4	5
59	1	2	3	4	5
60	1	2	3	4	5

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